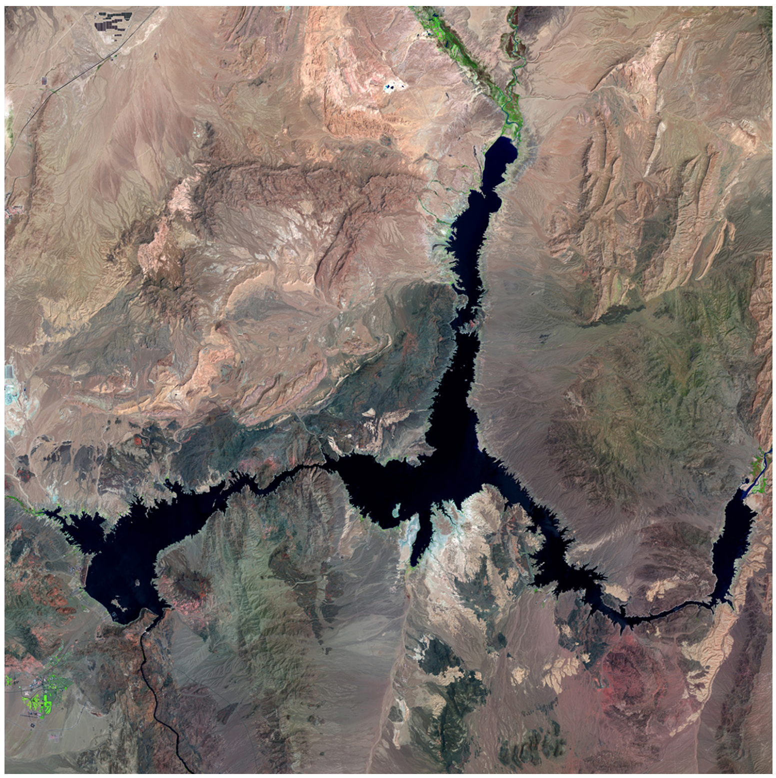


3 RESEARCH FOR SOCIETAL NEEDS

RESEARCH FOR SOCIETAL NEEDS

USGCRP's annual priorities respond to emerging challenges that tie science to society, supported by long-term Program investments in observations, modeling, process research, and actionable and accessible science. These priorities extend across agencies, scientific disciplines, and USGCRP's four strategic goals. They also answer the call from the President's Climate Action Plan to provide emerging science on climate impacts, identify vulnerabilities in key sectors, develop information and tools that decision makers need, and help communities manage climate-related risks. Annual priorities build upon previous progress, with continual refinements to fill gaps in understanding and address ongoing challenges from new angles.

USGCRP has three thematic priorities for Fiscal Year (FY) 2017, two building from previous fiscal years and one new, respectively: understanding the impacts of climate change in the Arctic and their effects on global climate, water cycle extremes in the context of climate change, and methane cycling in the context of the carbon cycle. This section provides a snapshot of Program activities that respond to each priority area. Research objectives are discussed in greater detail in the following chapter, A Look Ahead at FY 2017.

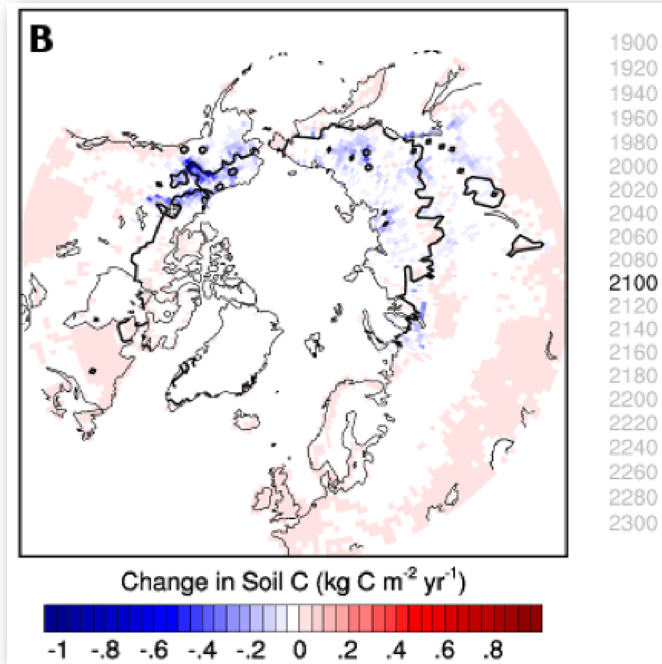
Arctic Research and Resilience

Recent observations confirm the heightened pace of climate change occurring in the Arctic, its profound impacts on Arctic ecosystems and communities, and its influence on global climate change. Global effects of Arctic change include sea-level rise, significant contribution to planetary warming, potential alteration of global weather patterns, and direct effects on the budget of global greenhouse gases, including methane. Large carbon stocks in frozen Arctic soils are particularly vulnerable to release as methane or carbon dioxide as the climate warms, and may have substantial climate feedbacks, further increasing warming and carbon release. Efforts are underway to reduce uncertainties surrounding the processes that control these feedbacks, and to better understand how much they could contribute to climate change *(Highlights 25-26)*.

In cooperation with other interagency groups, USGCRP emphases in FY 2017 include a focus on understanding Arctic ecosystem change and resulting societal vulnerabilities and on how change in the Arctic region influences weather and climate extremes, along with the use of Arctic assessments to support decision makers. Progress in these areas will contribute to U.S. goals as it completes its two-year term as Chair of the Arctic Council in the spring of 2017.

Highlight 25. Modeling Permafrost Response to Climate Change

Vast quantities of carbon—twice the size of the current amount in the atmosphere—are stored in frozen permafrost soils in Arctic regions. The Arctic climate is warming much more rapidly than the global average, leaving these carbon pools highly vulnerable to release into the atmosphere as carbon dioxide and methane as soils thaw and decompose, leading to a feedback cycle of further warming and increasing carbon release. The potential for these carbon stocks to increase global-warming rates, and the rapid changes already observed in the permafrost region, have captured the attention of scientists and policymakers. Scientists funded by several USGCRP agencies are working to quantify emissions from permafrost carbon, using observations and modeling to reduce uncertainties surrounding future carbon release. The Permafrost Carbon Network (PCN), with participation from USGCRP agencies and multiple countries, is working to evaluate the state of models that represent permafrost-carbon dynamics, and identify common approaches for improving model skill.



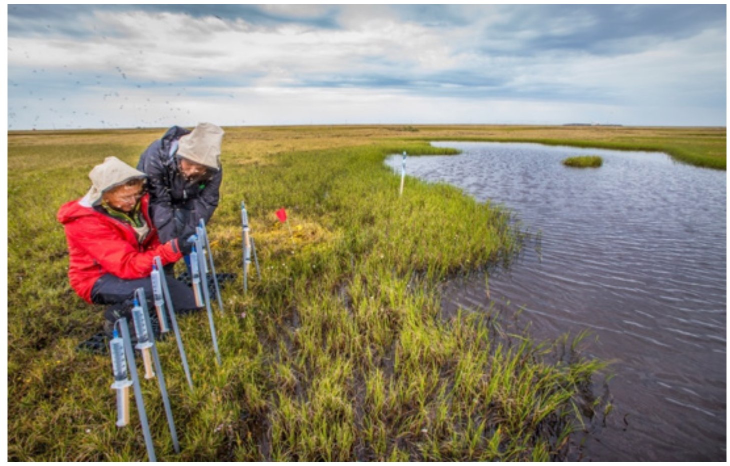
Model simulations showing the extent of permafrost loss and soil carbon change by 2100. As the climate warms, the permafrost boundary moves poleward; carbon losses from soils follow and loss rates persist long after the period of rapid thaw. (Source: Koven et al., 2015[21]).

Underlying many of the uncertainties surrounding permafrost carbon release is the need to better integrate observations into models. By synthesizing observational data and model outputs from multiple sources, recent PCN activities have found that permafrost-carbon feedbacks to global warming are likely to be strong but relatively slow, operating on timescales of about a century or longer, and that carbon stocks are unlikely to be released abruptly. Permafrost carbon release is likely to be roughly linear with warming, with a feedback magnitude of about one third of the total estimated global carbon-climate feedback. However, uncertainty surrounding key processes that control the feedback from permafrost is high, particularly with regard to changes in the water cycle and soil moisture conditions. Further critical uncertainties include the decomposition dynamics of thawed permafrost soils, and how vegetation response to changing soil conditions affects the stability of carbon stocks.

Across USGCRP agencies, many activities focus on translating understanding derived from observations into climate models. Together, the DOE-led Next-Generation Ecosystem Experiments in the Arctic *(Highlight 26)*, NASA's Arctic-Boreal Vulnerability Experiment *(Appendix III. Observations to Support Global-Change Research)*, and complementary activities from other agencies are helping advance understanding of permafrost response to warming, and its implications for regional and global climate change.

Highlight 26. Improving Predictions of Changing Arctic Ecosystems

A key challenge for Earth System Models is accurately representing land surface and subsurface processes and their complex interactions in a warming climate. This is true for ecosystems across the globe, but particularly critical for Arctic ecosystems, which are projected to warm at a rate twice that of the global average by the end of the 21st century. The Next-Generation Ecosystem Experiments in the Arctic (NGEE-Arctic) project is addressing this challenge by integrating process studies, ecosystem observations, and computational modeling to improve the ability to understand, model, and predict important ecosystem-climate feedbacks in the Arctic. This research focuses on rapidly changing permafrost landscapes where large carbon stocks are vulnerable to release as greenhouse gases. Field research sites in different types of permafrost environments in Alaska allow researchers to test and apply a framework for measuring and modeling the evolution of terrestrial ecosystems in a changing climate.



The Next-Generation Ecosystems Experiment in the Arctic is integrating ecosystem observations with computational models to better understand, model, and predict climatically-important feedbacks from Arctic ecosystems. (Source: DOE).

NGEE-Arctic draws upon expertise from across a consortium of DOE National Laboratories, academic institutions, and international, state, and Federal agencies. The project benefits from regional co-location of sites with the DOE Atmospheric Radiation Measurement program, the NSF National Ecological Observatory Network program, and NOAA's Earth System Research Laboratory, each of which provide valuable data resources. In addition, researchers from NASA's Carbon in Arctic Reservoirs Vulnerability Experiment and Arctic-Boreal Vulnerability Experiment campaigns *(Appendix III. Observations to Support Global-Change Research)* are using NGEE-Arctic field sites for validation of remote-sensing products and, in turn, providing opportunities to extrapolate insights from field plots to landscapes and ultimately, to regions. A focus on scaling will enable these interagency activities to deliver a process-rich model allowing the evolution of Arctic ecosystems in a changing climate to be modeled at high resolution.

Water-Cycle Extremes and their Impacts

Extremes in the water cycle impact all aspects of life on Earth, including food availability, infrastructure durability, human health, and energy production. As extreme weather and climate events become more frequent and more intense under a changing climate, basic and applied water-cycle science is increasingly vital to the health of the Nation. This research area addresses knowledge gaps that limit the ability to understand and predict the interplay between climate variability and change and extreme events associated with Earth's water cycle. In FY 2017, this priority includes a greater emphasis on assessing and anticipating the ecological impacts of such changes and their societal effects. This research area focuses on achieving a better understanding of changing patterns in both wet and dry extremes, including the impacts of, and responses to, such changes. In support of the President's Climate Action Plan, this priority will provide new knowledge that can be used for drought and flood preparedness and longer-term resilience strategies.

Efforts include research into the sources of variability in West Coast precipitation, which can lead to better predictive capabilities for droughts and floods *(Highlight 27)*, and research supporting drought prediction and the development of tools to communicate risk to stakeholders *(Highlight 28)*.

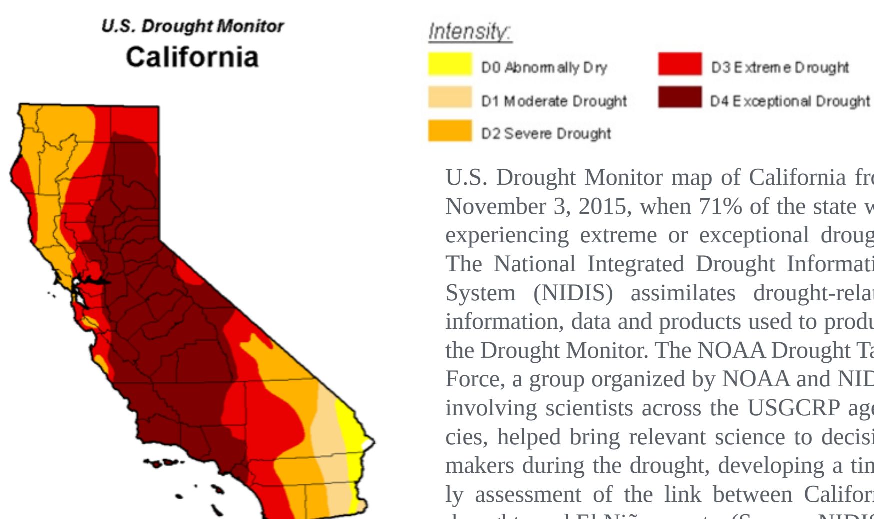
Highlight 27. Understanding Atmospheric Rivers and West Coast Precipitation

Much of the precipitation along the U.S. West Coast is delivered by phenomena known as "atmospheric rivers"—narrow bands of moist air that may extend for thousands of miles across regions outside of the tropics, and play a critical role in regional water supply and storm activity. Atmospheric-river events play a beneficial role in building up Western water supply and snowpack but are also the source of a large majority of floods in the region[22]. Many uncertainties about key processes that affect storm development within atmospheric rivers limit the ability to predict atmospheric rivers and associated precipitation. An improved understanding of these processes is needed to reduce uncertainties in weather predictions and climate projections of droughts and floods, both now and under changing climate conditions. From January-March 2015, the joint NOAA, NASA, and DOE CalWater-2 campaign collected a comprehensive dataset in environments where atmospheric rivers develop and make landfall, including data on how atmospheric aerosols influence precipitation.

Aircraft instruments sampled aspects of atmospheric rivers and their associated environment, and researchers aboard a NOAA Research Vessel operated NOAA and DOE instrumentation, measuring energy flow between the ocean and the atmosphere and its influence on atmospheric rivers. The campaign also built on the new NOAA Hydrometeorology Testbed (HMT) ground sites, which contributed measurements of precipitation, winds, snowpack, soil moisture, snow level, and surface weather. Scripps Institution of Oceanography installed additional instrumentation at the Bodega Bay HMT site to study aerosol chemistry. This data will be used to improve short- and long-term precipitation predictions and develop decision-support tools for extreme-precipitation events, hazard response, and water-resources management.

Highlight 28. Focusing on the California Drought

Since 2011, California has experienced one of its most severe and widespread droughts since record-keeping began in 1895. USGCRP-supported research helps advance drought science and provides the basis for the National Integrated Drought Information System (NIDIS) *(Highlight 10)*, which aims to increase the capacity of the public to better prepare for and respond to drought events through regional Drought Early Warning Systems (DEWS). The NOAA Drought Task Force, a group organized by NOAA and NIDIS involving scientists across the USGCRP agencies, helped bring drought science to decision makers. The group developed a timely assessment of the link between California droughts and El Niño events, of key relevance given the strong 2015–2016 El Niño. A new Task Force report demonstrates how research investments over the past decade have advanced the NIDIS DEWS and discusses opportunities



U.S. Drought Monitor map of California from November 3, 2015, when 71% of the state was experiencing extreme or exceptional drought. The National Integrated Drought Information System (NIDIS) assimilates drought-related information, data and products used to produce the Drought Monitor. The NOAA Drought Task Force, a group organized by NOAA and NIDIS involving scientists across the USGCRP agencies, helped bring relevant science to decision makers during the drought, developing a timely assessment of the link between California droughts and El Niño events. (Source: NIDIS).

for further progress in drought monitoring and prediction.

In addition, USDA-National Institute of Food and Agriculture and NOAA jointly funded a multi-university research team to work with agricultural producers and decision makers to better communicate the uses and limitations of currently available drought products, develop high-resolution drought-monitoring products tailored for planning purposes, and identify needs for new information products. USGCRP drought scientists also played a significant role in the American Geophysical Union Chapman Conference on the California Drought held in Irvine, California in April 2015. The conference examined the broad range of issues associated with the drought, including meteorological factors, the nature of California's water-delivery system, stakeholder needs and concerns, and policy and management solutions.

A Changing Carbon Cycle: Focus on Methane Cycling

Increased atmospheric concentrations of carbon-based greenhouse gases are the main driver of climate change. Methane is the second-most important greenhouse gas emitted by human activities and has a much higher global-warming potential than carbon dioxide on a per unit basis[23]. Both human activities and natural processes release methane into the atmosphere, but the details of each source are insufficiently understood. Further, methane's atmospheric lifetime is significantly shorter than that of carbon dioxide, meaning that steps to mitigate methane emissions could have a relatively more rapid impact.

Building on its Carbon Cycle Science Program, and in support of the President's Climate Action Plan Strategy to Reduce Methane Emissions, USGCRP has adopted an FY 2017 interagency priority that includes strengthening capabilities to monitor natural and anthropogenic methane fluxes, understanding processes governing significant methane emissions sources, and improving models and predictions of methane cycling in the context of the carbon cycle. Efforts include campaigns to measure the largest known methane leak in U.S. history *(Highlight 29)* and reduce uncertainties in seasonal and climatic controls on methane emissions in the Arctic tundra, a major global source of methane that may increase substantially with warming *(Highlight 30)*.

Highlight 29. Measuring the Largest Methane Leak in U.S. History

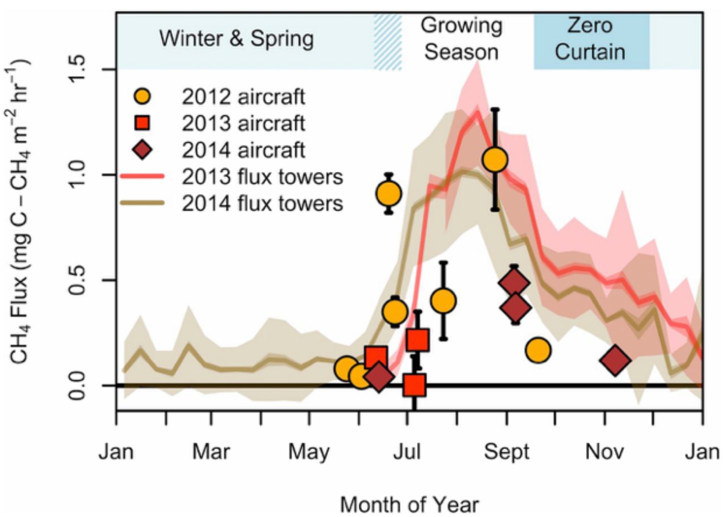
On February 11, 2016, workers in California ended the largest reported natural gas leak in U.S. history. The Aliso Canyon leak released methane and other gases into the atmosphere from an underground-storage facility for over three months, causing the evacuation of more than 5,000 households. Researchers from NOAA, NASA, Scientific Aviation, the University of California, the National Institute of Standards and Technology (NIST), the California Air Resources Board, and South Coast Air Quality Management District mobilized rapidly to assess the environmental impacts of the leak, deploying existing measurement capabilities to quantify how much methane, a potent greenhouse gas, was escaping. The interagency response to this incident demonstrated the application of multiple, independent methane-measurement methods to address challenges ranging from rapid response to unplanned events, to ongoing emissions monitoring and characterization of emissions sources at fine scales.

Thirteen research flights provided an unprecedented opportunity to document the total amount of methane released over the 112-day leak. A study co-led by NOAA, published in Science just two weeks after the leak was stopped, estimated that about 97,000 tons of methane were released—one quarter of the methane that is typically emitted by the entire Los Angeles Basin over the course of a year—making the leak the largest reported accidental release of methane in U.S. history[24]. In addition, the Hyperion instrument on NASA's EO-1 satellite and NASA research aircraft successfully detected and quantified the leak plumes at high spatial resolution[25].

Instrumentation deployed through the Megacities Carbon Project *(Highlight 5)* provided data on background methane emissions in the area and documented abnormally large methane plumes crossing the Los Angeles basin during the Aliso Canyon incident. Analysis using data from the Megacities tower network and NASA's California Laboratory for Atmospheric Remote Sensing is underway to develop a record of methane emissions sufficient to attribute fluxes to the vicinity of the Aliso Canyon facility. These analyses will evaluate the potential for smaller emissions in the weeks preceding the leak onset, the potential for highly variable fluxes associated with early "top-kill" attempts to stop the leak, and subsequent evolution of the leak flux before and after the successful "bottom-kill" closure. Data from remote-sensing instrumentation mounted on aircraft is also being combined with NIST plume modeling to estimate emissions fluxes. Future analyses and synthesis of these data sets will further explore the physical mechanisms controlling methane leak rates and their potential broader applicability to other underground gas-storage facilities.

Highlight 30. Tracking Methane Emissions from Arctic Tundra

The Arctic tundra is a cold, desert-like biome, with a layer of permanently frozen soil and organic matter below the surface containing vast stocks of carbon. As Arctic tundra soils warm in response to climate change, methane emissions from decomposing organic material could increase dramatically, representing a potentially significant positive feedback on climate warming. However, seasonal and climatic influences on methane emissions from these systems are not well understood outside of the summer months, representing a major uncertainty for the Arctic methane budget. To help address a critical knowledge gap in cold-season methane emissions, a coordinated international, multiagency field study sponsored by NASA, NSF, and DOE made year-round measurements of methane emissions from Alaskan Arctic tundra eddy covariance towers and regional flux estimates from aircraft data. Recent findings report that emissions during the cold season account for approximately 50% of the annual methane flux, with the highest emissions from dry upland tundra[26].



Ten-day average of methane (CH_4) flux measured by five eddy covariance (EC) towers over a 300-kilometer transect across the North Slope of Alaska (shaded bands) for 2013 (red) and 2014 (brown), with the mean (solid line), 95% confidence intervals (darker shade), and standard deviation in the CH_4 data (lightest shade). The regional fluxes of CH_4 calculated from Carbon in Arctic Reservoirs Vulnerability Experiment aircraft data for the North Slope of Alaska are shown for 2012 (yellow circles), 2013 (red squares), and 2014 (brown diamonds). The mean dates for the onset of winter, the growing season, and the zero curtain are indicated in the band on top. Regional scale methane fluxes showed similar seasonal patterns to the five EC flux towers across multiple years. (Source: Zona et al. 2016).

Scaled to the global Arctic, cold-season fluxes from tundra represent about 25% of global emissions from wetlands outside of the tropics, or about 6% of total global wetland methane emissions.

Emissions of methane in the cold season are linked to the extended “zero curtain” period, when subsurface soil temperatures are poised near 0° Celsius, indicating that total emissions are very sensitive to soil conditions and related factors, such as snow depth. The dominance of late-season emissions, sensitivity to soil environmental conditions, and importance of dry tundra are not currently simulated in most global climate models. Because Arctic warming disproportionately impacts the cold season, results suggest that higher cold-season methane emissions will result from observed and predicted increases in snow thickness, active-layer depth, and soil temperature, representing important positive feedbacks on climate warming.